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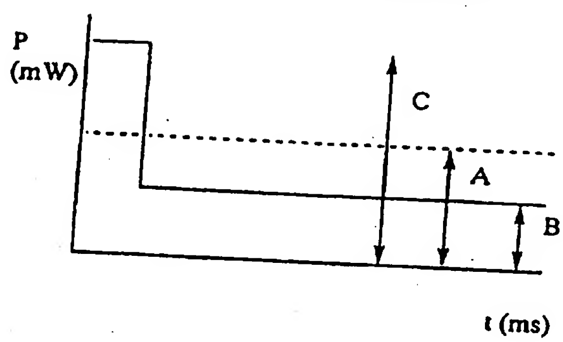

(57) Abstract

The invention pertains to a method for switching an optical signal from a digital thermo-optical switch input port to at least one output port of the switch, with a temperature difference being imposed between at least two of the output ports, and with said temperature difference at the outset being greater than or equal to ΔT_{min} (the minimum difference required for switching) and subsequently being reduced to one of less than ΔT_{min}. This switching scheme greatly reduces the thermal load on the digital thermo-optical switch.

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METHOD FOR SWITCHING OPTICAL SIGNALS AND A THERMO-OPTICAL SWITCH

The invention pertains to a method for switching an optical signal from an input port of a digital thermo-optical (TO) switch to at least one output port of the switch, with a temperature difference being imposed between at least two output ports.

Such a method is known from N. Keil, et al., "(2x2) digital optical switch realised by low cost polymer waveguide technology," Electronics Letters, Vol. 32, No. 19 (1 August 1996), pp. 1470-1471. In this document a thermo-optical switch is described which has four waveguides (or, more accurately, waveguide channels), two input ports and two output ports, and four electrodes for heating the waveguides. Switching a signal from one of the input ports to one of the output ports is effected via selective heating of the waveguides.

In addition to this 2x2 switch there are, int. al., 1x2 (e.g., "Y branched") thermo-optical switches. In one embodiment a "single mode" signal is switched from the input port to one of the output ports by heating only one of the output ports, in other words, by inducing a temperature difference, and consequently a difference in index of refraction, between the output ports. In the most common switches the signal will travel through the waveguide which has the highest index of refraction. In the case of polymeric digital thermo-optical switches that means the waveguide which has the lowest temperature (and therefore the highest density).

After switching, the switch is in the envisaged position and the temperature difference is maintained. In actual practice, an electrode serving as a

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heating member is driven at a certain voltage, which voltage is kept constant (in other words, the switch is step-function driven).

In thermo-optical switches a phenomenon may be encountered which occurs in particular when a thermo-optical switch has been in the same state for a long period of time (days to years), which phenomenon is best described as "remanent induced junction asymmetry."

To illustrate this phenomenon use is made of a 1x2 ("Y-branched") polymeric digital thermo-optical switch such as is depicted schematically in Figure 1. This switch 1 comprises an input port 2, a left-hand output port 3, a right-hand output port 4, and electrodes 5 (shown here in a finer version than the electrodes customary in actual practice) for heating the output ports 3, 4.

A signal S2 in the input port 2, is sent to the left-hand output port 3. In that case electrode 5 of the right-hand output port 4 is heated. At an isolation (i.e., the difference in power of the signals travelling through the respective output ports of the switch) of 20.0 dB, 1% of the signal S2 is guided to the right-hand output port 4, while 99% of S2 is guided to the left-hand output port 3 (10 log (99/1) = 20.0 dB). When the electrode 5 of the right-hand output port 4 is no longer driven, the switch ideally will return to the ground state. In this state the switch functions as a passive splitter which divides the signal S2 equally (50%/50%; isolation 0 dB) between the two output ports 3, 4.

It was found that thermo-optical switches which are in the same state for a long time fail to revert to the aforesaid ground state after the driven electrode has been switched off (or fail to do so within an acceptable period of time), reverting instead to an asymmetric state in which over half of the

S2 signal is still guided to, in this example, left-hand output port 3. The switch thus continues to have a certain bias for its previous state. Even when electrode 5 of the left-hand output port 3 is driven at the aforementioned voltage and causes a temperature difference between the output ports, this asymmetry is not overcome (rapidly) enough, and it is no longer possible to achieve the prescribed isolation.

In such cases switching can still be carried out by an extra increase in the voltage over the electrode, but this requires intensive monitoring of the switch (which is subject to practical objections) and comparatively complex driving means. Moreover, when the voltage is increased more than once, the asymmetry may be subject to resonant rise and finally reach a level at which the switch will be rendered unsuitable for use.

In a number of TO switch applications switching takes place only under (comparatively) rare conditions. Good examples of this are protection and redundancy, where the switch will always guide a signal to one and the same optical fibre, except when there is a problem, such as damage to the fibre. In such a case the switch will be turned and the signal guided to a second, undamaged fibre. If proper switch action in such an application cannot be guaranteed, the whole redundancy system is pointless. In other words, the value of such a system is greatly dependent on the reliability of the switch.

In view of the above there is need for a method for switching thermo-optical switches in which the increase in remanent induced junction asymmetry does not occur or occurs only to a very much lower extent. The invention has for its object to satisfy this need and achieves this when in the method described in the opening paragraph the (temperature) difference is greater than or equal to ΔT_{min} at the outset and is subsequently reduced to a

difference of less than ΔT_{min}, with ΔT_{min} being the minimum temperature difference required for switching.

It was found that the described remanent induced junction asymmetry of thermo-optical switches is linked to the heat supplied. In general, it holds that this asymmetry will increase less rapidly as the supplied power (which is converted into heat and results in a temperature difference) is lower. Preferably, the power is reduced to a level where the temperature difference between the output ports of the switch is lowered to a difference which is at least 10%, or even at least 20%, less than ΔT_{min}.

Besides reducing the remanent asymmetry, the reduction of the heat supply is advantageous in itself because the thermal load on the switch (especially on the electrodes) is reduced and less power is consumed.

Given the action of thermo-optical switches, the possibility of reducing the power supply to a value which produces a temperature difference of less than ΔT_{min} without any substantial change to the switching effectiveness (isolation) may be deemed remarkable. It was found that thermo-optical switches (in particular those made of a polymer) exhibit hysteresis, which means that the temperature difference which is required over the output ports to increase the isolation between two output ports to above a specific value (in brief: the temperature difference required for switching) is higher than the temperature difference at which the isolation drops below said value (and at which the switching is cancelled).

It should be noted that the answer to the question of whether switching has been completed or not is dependent on the specifications or the given use of a switch. If the specifications of a particular switch list an isolation of 15 dB minimally, this means that, in the case of a 1x2 switch, after completion

of the switching procedure (which, ordinarily, lasts less than 5 ms) less than 3% of the power of the signal which is supplied to the switch passes through the output port which is qualified as being in the "off" state, while over 97% of the signal passes through the output port qualified as being in the "on" state.

It will be clear from the above that the term "switched" does not so much stand for an absolute physical state but rather indicates that the present switch meets the specification (in this case especially the isolation) of the switched state. Hence the isolation can be required by the specifications of the switch or its application. For instance, a switch may allow an isolation of 30 dB, while 18 dB will suffice for a specific use. In that case, 18 dB will be normative in that case.However, it is preferred that at ΔT_{min} the isolation is at least 16 dB, preferably at least 25 dB.

The effects of the present invention are especially noticeable in polymeric switches (i.e., those switches in which at least the waveguides, but usually also the cladding(s), consist of an organic polymer). Further, for the method according to the invention it holds that it is preferred to use switches which allow an isolation in the switched state of greater (better) than 16 dB, or even of greater than 25 dB.

As was described above, in the process according to the invention a (temperature) difference is imposed at the outset which is greater than or equal to ΔT_{min}, which difference is subsequently reduced. Preferably, the difference is reduced as soon as possible after switching, but the time in question should at least be long enough to guarantee the effect of the invention. The period of time involved is dependent on the switch itself, but also on the temperature of the entire switch (the higher this temperature is, the faster the temperature difference over the output ports of the switch can

be reduced). In many cases (especially when use is made of polymeric waveguides) it will be possible to reduce the difference after less than 0,1 to 0,5 seconds. It is preferred, particularly in the case of applications in which little switching occurs, not to do this until after 5 seconds, or even after 10 seconds.

For that matter, it holds that the build-up of remanent induced junction asymmetry manifests itself less strongly as the temperature of the entire switch is higher. In one embodiment according to the invention the entire switch is kept at a temperature above 40°C, preferably above 60°C. To this end the switch may be equipped, e.g., with one or more heating members and an insulating material.

To reduce the period of time after which the temperature difference can be reduced and also reinforce the effect of the method according to the invention further, it is recommended to have a temperature difference at the outset of more than 20%, or even 50% or 100%, greater than ΔT_{min}. Shortening the pulse will make the switch less susceptible to switching conditions out of the ordinary (e.g., alternating high and low frequencies and/or irregular switching).

The magnitude of ΔT_{min} is made up at least of the temperature difference needed to bring a switch which is in the aforementioned ground state (isolation 0 dB) to the switched state and an additional temperature difference needed to quickly overcome the previous switched state (in milliseconds). ΔT_{min} may vary per switch (geometry, materials used, etc.) and furthermore is dependent on what happened before, so that it is also possible for ΔT_{min} to vary in time in one and the same switch.

It should be noted that it is not possible to select just any high supply of power to the switch. At a certain high power, susceptibility to polarisation will come to play an increasingly important role. For that reason preferably the power used is not such as will create a temperature difference over the output ports of the switch of 400% greater than ΔT_{min}.

The method according to the invention is depicted schematically in Figure 2. In the polymeric digital thermo-optical 1x2 switch according to Figure 1 a signal S2 is presented, and electrode 5 of the right-hand output port 4 is energised with a voltage of, say, 4 V. As a result, power having a magnitude A is supplied to electrode 5. This power creates a temperature difference between the output ports 3 and 4 equal to ΔT_{min}.

After 2 ms 99.91% of the power of signal S2 is directed to the comparatively cool left-hand output port 3 (the isolation thus is just above 30 dB, i.e., at a prescribed isolation of ≥ 30 dB it is now possible to speak of a "switched state"). Ordinarily speaking, the supplied power A would remain unchanged over time. According to the invention, the voltage over electrode 5 is reduced after 4 seconds to 2,5 V, causing the power to decrease to B (B ≈ 0,6 x power A), whereas the isolation remains just above 30 dB.

The power C (≈ 1,5 x power A) depicted in Figure 2 is an example of the above-described temperature difference peak. Because of this peak the voltage can be reduced to B already after one second without the isolation being adversely affected even in the longer term.

An additional advantage of the method according to the invention is that it can also be employed with TO switches which are already in use. In many cases the advantages of the invention, in particular the longer life of the

switch, are still obtainable by simply replacing or adjusting the drive of the means for heating the output ports.
For completeness' sake it should be noted that there is a major distinction between inherent junction asymmetry and induced junction asymmetry.

Inherent asymmetry concerns asymmetry resulting from the switch's materials and geometry. For instance, in a 1x2 TO switch consisting of a waveguide running in a straight line and a branch (in contradistinction to the "Y-branched" switches where, in a sense, there are two branches), an isolation of 6 dB can be measured without any of the electrodes being "on."

Induced asymmetry concerns asymmetry resulting from the thermo-optical effect brought about by the supply of heat and the imposition of a temperature difference between the branches or output ports. Needless to say, the two types of asymmetry can be present in a switch simultaneously.

Nor is the invention restricted to one particular type of TO switch; rather, it comprises NxM (N and M both are integers) and 1xN switches. In principle, preference is given to 1x2 switches (such as the "Solid state 1x2 optical switches" or BeamBox™ ex Akzo Nobel) and matrices comprising 1x2 switches. Suitable (polymeric) switches are disclosed, int. al, in European patent applications 95200965.2, 95201460.3, 95201762.2, and 95201761.4.

It should be noted that Japanese patent appication 59 148031 discloses an optical switch which is operated using a temperature-gradient generating means and a voltage source for supplying a voltage larger than the steady ON state voltage at the time only of ON rise. Subsequent reduction of the voltage to a value below the steady ON state voltage is not disclosed.

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The invention further relates to a digital thermo-optical switch comprising at least one input port, at least two output ports, elements for imposing a temperature difference between at least two of the output ports, and means for driving said elements, which means (preferably an electrical circuit) drive the elements in such a way that, in response to a stimulus, the temperature difference at the outset is increased to a value greater than or equal to ΔT_{min} and the difference is subsequently reduced to a difference of less than ΔT_{min}, with ΔT_{min} being the minimum temperature difference required for switching. It is preferred that at ΔT_{min} the isolation is at least 16 dB, preferably at least 25 dB.

Preferably, the temperature difference is reduced to a difference of at least 10% less than ΔT_{min} and/or the temperature difference at the outset is at least 20% greater than ΔT_{min}.

Polymeric switches are preferred. Further, if the digital thermo-optical switch has an isolation which is greater (better) than 16 dB, preferably greater than 25 dB, the losses in the switch will remain within acceptable limits and the switch is suitable to be used in virtually any application.

Claims

1. A method for switching an optical signal from an input port of a digital thermo-optical switch to at least one output port of the switch, with a temperature difference being imposed between at least two of the output ports, characterised in that the temperature difference at the outset is greater than or equal to ΔT_{min} and is subsequently reduced to one of less than ΔT_{min}, with ΔT_{min} being the minimum temperature difference required for switching.

2. A method according to claim 1, characterised in that at ΔT_{min} the isolation is at least 16 dB, preferably at least 25 dB.

3. A method according to claim 1 or 2, characterised in that the temperature difference is reduced to one which is at least 10% less than ΔT_{min}.

4. A method according to any one of the preceding claims, characterised in that the switch is polymeric.

5. A method according to any one of the preceding claims, characterised in that the temperature difference at the outset is maintained for at least 5 seconds.

6. A method according to any one of the preceding claims, characterised in that the temperature difference at the outset is at least 20% greater than ΔT_{min}.

7. A method according to any one of the preceding claims, characterised in that the switch is of the 1x2-type.

8. A digital thermo-optical switch comprising at least one input port, at least two output ports, elements for imposing a temperature difference between at least two of the output ports, and means for driving the elements, characterised in that the means are arranged to drive the elements such that the temperature difference at the outset is greater than or equal to ΔT_{min} and is subsequently less than ΔT_{min}, with ΔT_{min} being the minimum temperature difference required for switching.

9. A digital thermo-optical switch according to claim 8, characterised in that at ΔT_{min} the isolation is at least 16 dB, preferably at least 25 dB.

10. A digital thermo-optical switch according to claim 8 or 9, characterised in that the temperature difference is reduced to one which is at least 10% less than ΔT_{min}.

11. A digital thermo-optical switch according to any one of claims 8 to 10, characterised in that the temperature difference at the outset is at least 20% greater than ΔT_{min}.

12. A digital thermo-optical switch according to any one of the claims, characterised in that the switch is polymeric.

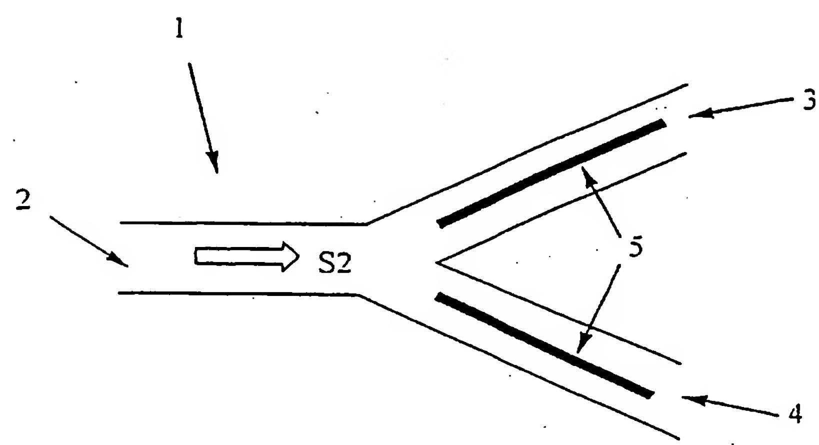

FIG. 1

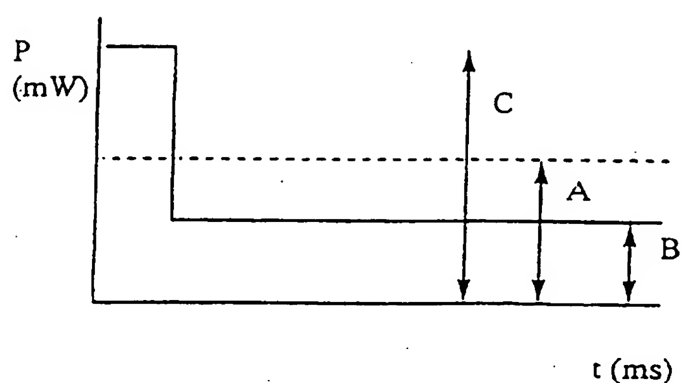

FIG. 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP [illegible]5359

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 642 052 A (AKZO NOBEL NV) 8 March 1995 see examples 2,3 ---	1,8
A	LIPSCOMB ET AL.: "Packaged thermo-optic polymer 1*2 switch" CONFERENCE ON OPTICAL FIBER COMMUNICATION (OFC'95), SAN DIEGO, TECHNICAL DIGEST, vol. 8, 26 February 1995, pages 221-222, XP002031581 see the whole document -----	1,8

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INTERNATIONAL SEARCH REPORT

International Application No
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		JP 7084226 A	31-03-95

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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 008, no. 282 (P-323), 22 December 1984 & JP 59 148031 A (TATEISHI DENKI KK), 24 August 1984, see abstract; figure 7 ---	1,7,8
A	M.B.J.DIEMEER ET AL.: "Polymeric optical waveguide switch using the thermooptic effect" JOURNAL OF LIGHTWAVE TECHNOLOGY, vol. 7, no. 3, March 1989, pages 449-453, XP002031580 see page 452, right-hand column, line 33 - page 453, left-hand column, line 3 ---	1

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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